EXPERIMENTAL TEST AND FINITE ELEMENT MODELLING OF PEDESTRIAN HEADFORM IMPACT ON HONEYCOMB SANDWICH PANEL

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Abstract

This paper represents a Finite Element model of Cellbond's aluminium honeycomb sandwich panel and proposes an original technique to develop the material characteristics which realistically simulate a child headform impacting on a sandwich panel. As part of a major study to develop a pedestrian friendly car bonnet design, this investigation has been carried out with the requirement as detailed in the EEVC regulations. Thus, all specimens have been impacted at specific angle and test speed using pedestrian head impactors. The Finite Element solution is based on the numerical simulation using the explicit FEA code DYNA3D, therefore, several preliminary tests were carried out to characterise the composite panel (honeycomb and adhesive) material properties used in the FE models. Results from preliminary component tests were used to describe the Modified-Honeycomb and Adhesive material cards. The final comparison of results from the experimental and numerical investigation represents a good correlation for the child impactor.

Introduction

Most pedestrian crashes involve a forward-moving car. In such a crash, the pedestrian is initially impacted by the car and then by the ground and most of the fatal injuries occur because of the interaction with the car. Thus vehicle designers usually focus their attention on understanding the car-pedestrian interaction, which is characterised by the following sequence of events. Hence pedestrian safety codes have always been communicated to the car manufacturers by vehicle safety legislations. In Europe, pedestrians account for around 20 % of all traffic fatalities [1]. In the rest of the world this frequency varies from 14 % in USA up to 47% in Thailand in which the majority of pedestrian fatalities are because of head impacts [2]. Today's cars are densely packed under the bonnet and certain rigid parts such as, the spring tower and the top of the engine, are close to the bonnet. Most serious head injuries occur when there is insufficient clearance between the bonnet and the stiff-underlying engine components. A small gap is usually enough to allow the pedestrian's head to have a controlled deceleration and a significantly reduced risk of death [3]. The European Enhanced Vehicles Committee (EEVC) Working Groups 17 has recommended several specific test methods to evaluate pedestrian protection which passenger cars must offer (Figure 1).

Euro NCAP introduced an evaluation criteria in 1996 [1] to assess the level of pedestrian protection. The Head Injury Criteria (HIC) value describes how quickly and how severely a dummy head is decelerated when it hits the bonnet of a car and is calculated using the formula below:

$$HIC = \max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} (t_2 - t_1) \qquad \text{(Eq.1)}$$

Where t is the impact time and $a(t)$ is the deceleration as a function of time. At Cellbond a study on the feasibility of a pedestrian friendly bonnet design has been conducted and disseminated in the company's literature. One appearance of this design investigated here is based around Cellbond's aluminium sandwich panel with impacting headform in accordance to EEVC regulations.

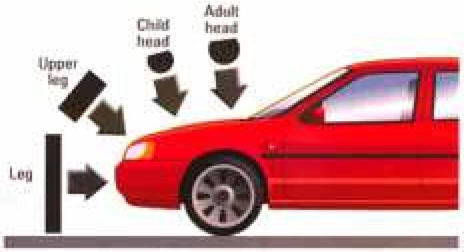


Figure 1. EuroNcap and EC Directive Tests

This paper presents a Finite Element model and method to create material properties to simulate child headform impact on a composite aluminium honeycomb panel. The Finite Element study is based on the numerical simulation using an explicit FEA code DYNA3D. Several preliminary tests were carried out to characterise the honeycomb block and adhesive material properties to impose in the FE models. Results from angled static compressive tests are consequently used to describe the yield surface function and stiffening parameters in the Modified-Honeycomb-Material card to perform an orthotropic material with different properties at dissimilar axis. Adhesive material card has also been obtained using Climbing Drum, T-Peel, Tensile and Plate Shear test results. The final comparison on outputs represents a good correlation between test data and CAE results for the child impactor.

Experimental Test Conditions

The honeycomb sandwich panels have been tested following the EEVC Working group 17 testing method. The Free Motion Headform Test system (FMHT) used for the dynamic impact tests consists of a firing mechanism that is fully programmable via a control panel (figure 2). The panels were clamped on four points in the support frame and the data was acquired from three accelerometers mounted within the head impactor. The target panels were supplied with specifications shown in table 1. The head impactor was fired at 50^o to the ground reference level while the firing speed was 11.1 m/sec^2. The child headform impactor is based on aluminium semi-sphere covered by thick vinyl skins which covers the impacting area of the headform. Three uniaxial accelerometers were mounted at the centre of gravity in order to measure acceleration in the respective directions. The overall mass of the impactor was fixed on 2.5 kg.

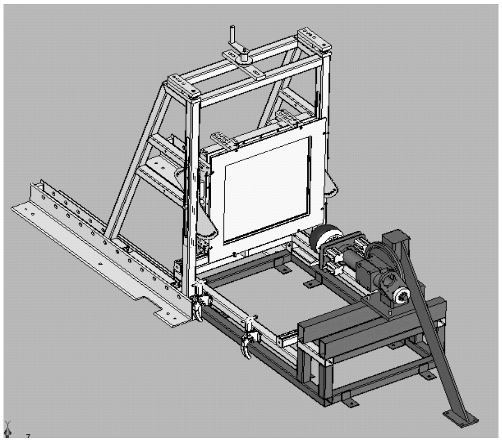
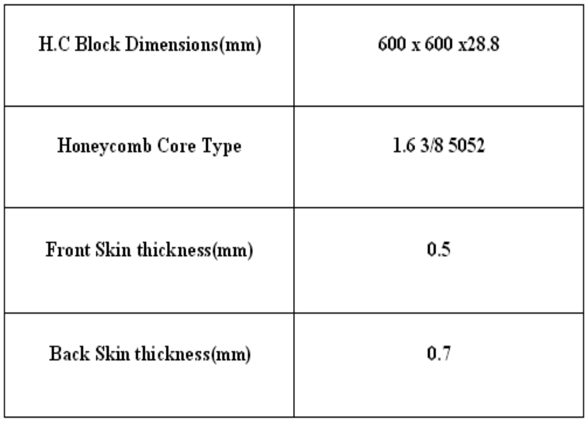


Figure 2. FMHT system



H.C Block Dimensions(mm)	600 x 600 x28.8
Honeycomb Core Type	1.6 3/8 5052
Front Skin thickness(mm)	0.5
Back Skin thickness(mm)	0.7

Table 1. Test sample specification

Component Tests

Number of angled static compressive tests were performed to describe the yield surface function and characterize the Modified-Honeycomb-Material card in the FE model of panel. Figure 3, illustrates the test arrangements for different angled section of the honeycomb blocks. The composite material used in the static tests was Cellbond’s 1.6 3/8 3003 aluminium honeycomb and the block dimensions were 200 mm x 180 mm x 50 mm which was tested at speed of 10 mm/min. Plot 1, shows the crush strength of used aluminium honeycomb in different cut section angles. The highest compressive stress was measured in zero degree (strong axis) and as the angle increases, the compressive stress decreases while the 35 degrees cut section represents almost half of normal core strength.

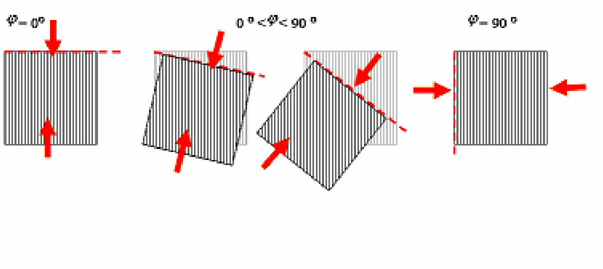
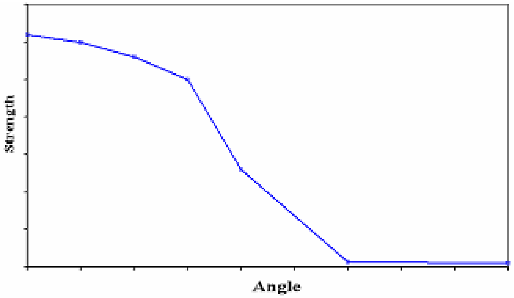


Figure 3. Static angled compressive test



Plot 1. Compressive stress vs. cut angle

The results from Climbing Drum, T-Peel, Tensile and Plate Shear tests were used to obtain material data and compose the adhesive characteristics. The Climbing drum test (Figure 4a) determines the resistance offered by the joints to perpendicular peel stresses on the adhesive layer [4]. It has been performed on a joint between aluminium sheet and the honeycomb panel. The T-peel [5] test method determines the relative peel resistance of adhesive (Figure 4b). This experiment enables to measure the strength required to separate two bonded members progressively and to analyse the type of failure.

a) Climbing Drum test **b) T-Peel test**

Figure 4

Finite Element Model and Analysis

Despite having some reliable modelling methods to simulate honeycomb crush behaviour [6, 7], it becomes time-consuming to create and solve complex geometries with various boundary conditions. Recruiting the Modified-Honeycomb-Material (Mat 126) card and modelling the honeycomb parts with solid elements creates an efficient way to solve the model. However, accurate material data in different formats are needed. The yielding function technique has given well-mannered results in investigations of AE-MDB [8] and ODB [9] crash barriers. In this method the yield stress of honeycomb is a function of different parameters [10] as described in equation 2.

$$\sigma^{y}(\varphi,\varepsilon^{vol}) = \sigma^{b}(\varphi) + (\cos\varphi)^{2}\sigma^{s}(\varepsilon^{vol}) + (\sin\varphi)^{2}\sigma^{w}(\varepsilon^{vol}) \qquad \text{(Eq.2)}$$

in which

φ = Section angle with the strong axis

$\sigma^{b}(\varphi)$ = Yield stress as a tabulated function of section angle

$\sigma^{s/w}(\varepsilon^{vol})$ = Stiffness as a tabulated function of volumetric strain

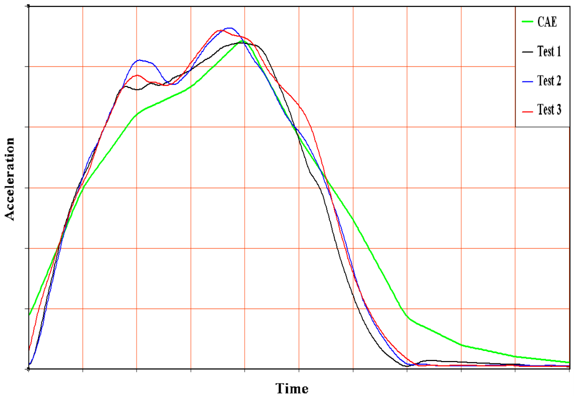
The Arup-Adhesive (Mat 169) material card was developed to simulate the connection between parts in which the yield and failure surface are treated as power-law of direct tension and shear across the bond (Equation 3).

$$\left(\sigma/\sigma_{\max}\right)^{\mathbf{n}} + \left(\tau/\tau_{\max}\right)^{\mathbf{n}} = 1.0 \qquad \text{(Eq.3)}$$

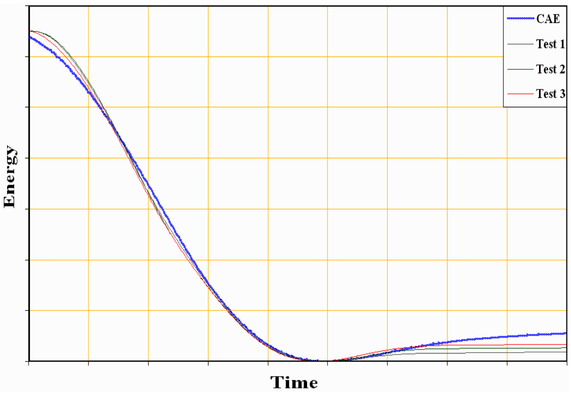
Where τ represents the shear stress and σ is the normal stress in adhesive.

Results

Graph 2, represents a comparison between experimental and FE analysis test results for deceleration rate of headform impactor. For these results the CFC60 filter was used to reduce local noises on original graphs. In both cases the component in the impact direction has been considered as comparison parameter. An acceptable consistency appears on test outputs and the FE model has created an appropriate correlation with experimental test data and gives a similar maximum deceleration rate.

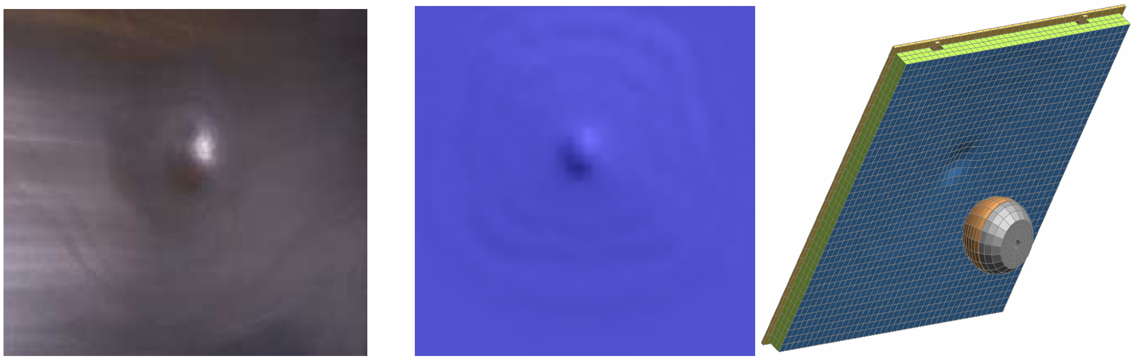


Plot 2. Headform acceleration vs. time



Plot 3. Headform Energy vs. time

Graph 3, also shows the kinematics energy dissipation during the tests and FE analysis in which there is not only a good constancy within the test data but, also an acceptable correlation has been achieved with the FE output. The headform impactor in FE model seems to run back in slightly higher speed after the impact. However, this is negligible as the overall result looks adequate. Furthermore, the energy absorption time appears to be the same for all specimens both in the experiment and the FE model. Figure 5, demonstrates a comparison of deformed panel in actual test and the developed model.



a) Experimental test **b) FE analysis**

Figure 5

Conclusion

An experimental and numerical study of child headform impact on a composite aluminium panel has been carried out. Several component tests were also performed to determine the material card data for the FE simulation. Analysis of the data for developed panel model shows a good numerical and visual correlation between FE model and experimental investigations. The yielding function technique to define the Mat 126 for honeycomb part with defined stiffening curves and Mat 169 for adhesive properties contributed a suitable performance and gave appropriate output compared to the experimental test data. The developed technique is a superior technique to regular non-linear analysis since the convergence time is reduced a great deal.

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